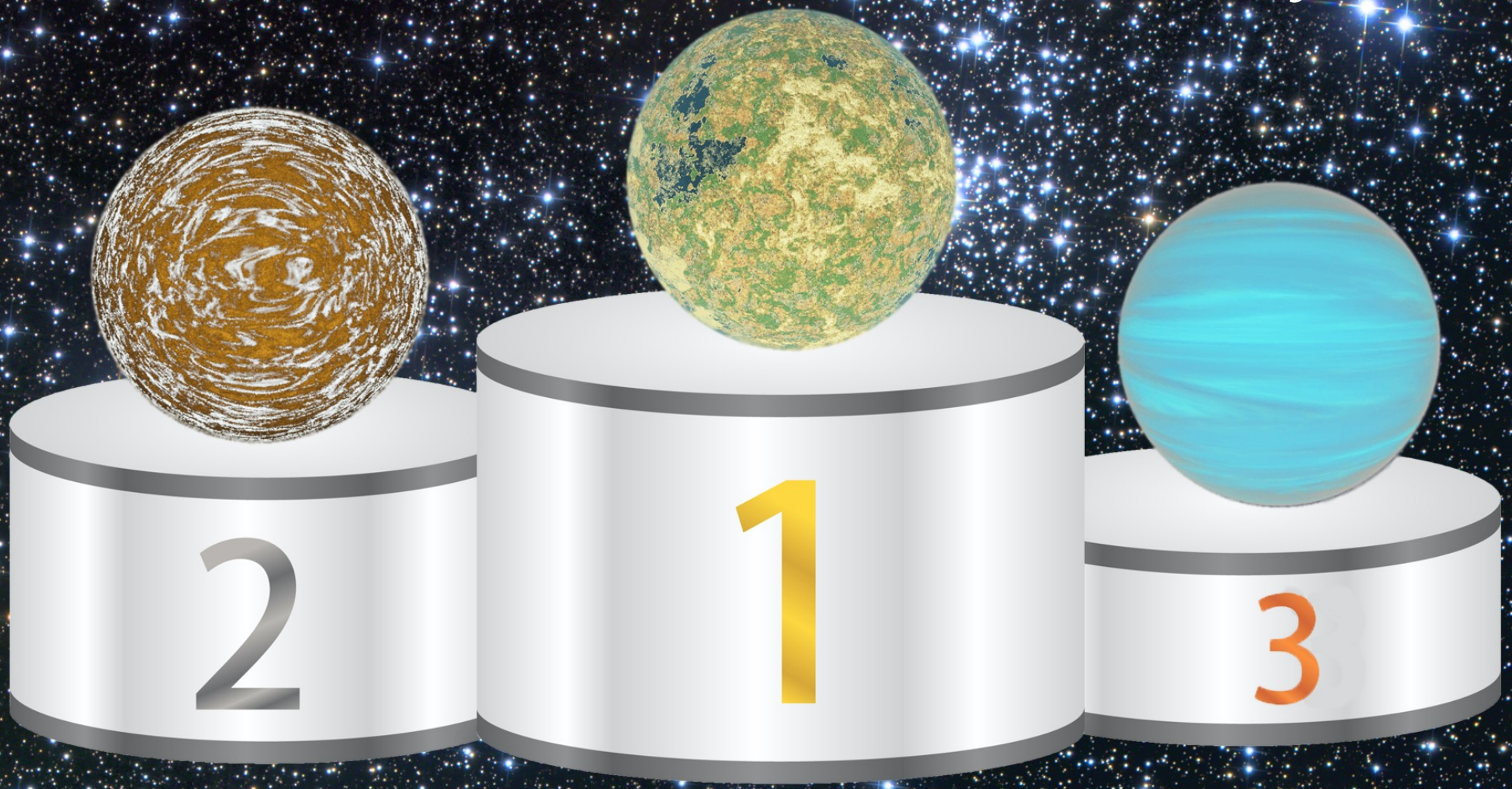
NExSS Quantitative Habitability



Rory Barnes (UW) & Danial Apai (UA)
Co-Leads

QuantHab SWG Cheat Sheet

- Goal is to articulate a framework for quantifying the likelihood that habitable conditions exist on an exoplanet
- First SWG to be proposed
- Formed in September 2020
- First chair Apai, now co-chaired by Apai and Barnes
- Bi-weekly meetings (Nov 2020 – Dec 2021), now monthly
- Slack channel, e-mail list, website (65 members)
- Workshop Dec. 2020 – 100 participants
- Now writing overview document on quantifying habitability

Quantifying Habitability

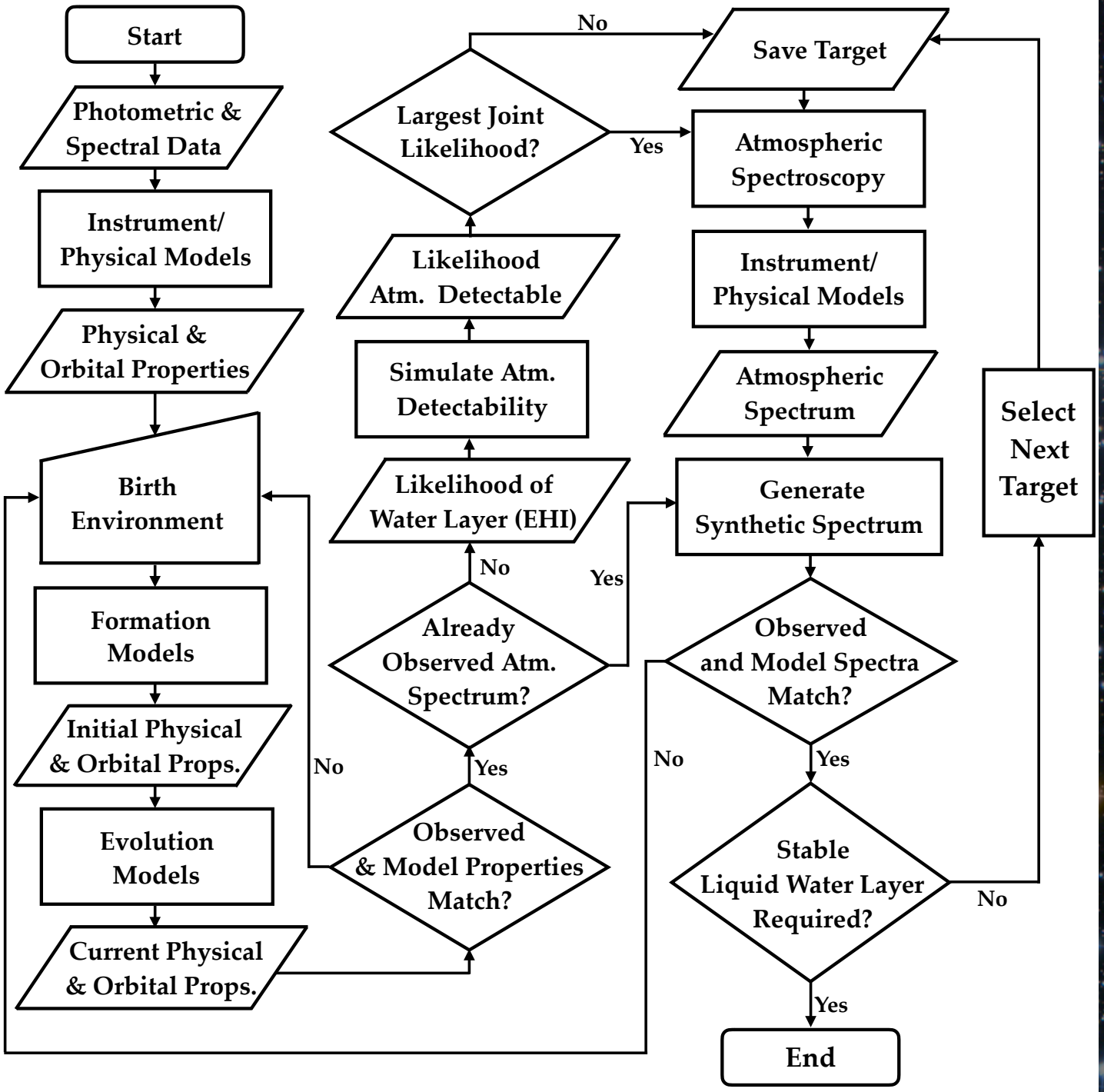
Today

Is a planet less than 1.5 R_E?
Is a planet in the HZ?

If yes, then potentially habitable!

The Future?

Employ a statistical framework that couples models of formation and evolution to observations in order to compute the likelihood (with uncertainties) that liquid water exists on the planet today



The Habitable Exoplanets Flow Chart

One *possible* approach to quantifying habitabiility

Bayesian: Posteriors from one process are priors for next

Many known unknowns – Will we trick ourselves?

Are there enough targets that ranking them makes sense?

- Might be more applicable in Luvex era and beyond

Ultimately want to also add life after the stable water step

Science Working Group Proposal

Quantifying Habitability by Integrating Multi-Domain Information

The assessment of planetary surface habitability is at the core of the search for life on exoplanets, but it remains a complex and poorly constrained problem. Constraints are now emerging, at an increasing pace, from observations and models of planet formation, planet evolution, stellar characterization, present-day atmospheric composition, as well as from exoplanet population statistics and specific, but necessarily incomplete and often uncertain information on the specific planet targeted. Future exoplanet characterization efforts will necessarily have to work with such incomplete information and an integrative approach will be key to correct quantitative and statistical interpretation of the potential surface habitability of given targets, also underpinning the interpretation of potential biosignatures.

The multi-disciplinary exoplanet communities continue to make rapid progress on focused research, but integrating evidence – often statistical in nature – across disciplines and sub-fields remains a major challenge. NExSS is uniquely well positioned to provide a hub and conduit for such an integrative effort.

We propose to start a Science Working Group to accomplish the following goals:
- Establish efficient channels of communication for the relevant groups
- Engage with and include as large fraction of the community as possible
- Identify and connect to existing resources and activities to avoid duplication and maximize efficiency
- Establish a centralized online hub to collect and organize relevant datasets, publications, links to groups
- Organize quarterly workshops focused on integrating quantitative knowledge on habitability

The EOS NExSS team will be able to provide logistical and organizational support for this effort for at least the years 2020 and 2021.

We foresee a review of the group's work and achieved results in about 18 months after the launch of the effort to, if needed, adjust goals, scopes, organization, or format.

Contact: Daniel Apai, UArizona, EOS/NExSS Team, apai@arizona.edu

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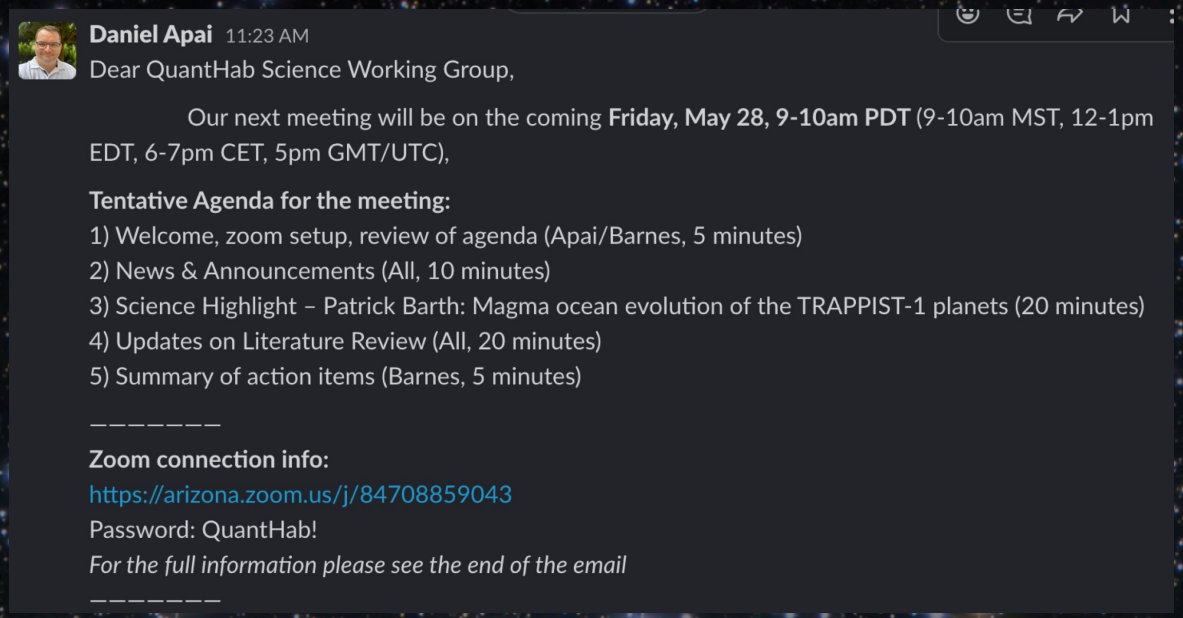
Communication channels:
- NExSS slack channel
- QuantHab email list
- QuantHab web page
- Biweekly meetings for 1.5 years
- "Science highlights" at meetings
- Workshop
- AAS Splinter Session proposed (canceled due to covid)

Online Hub
- Web page collecting resources, models, etc
- Moved to new NExSS site
- Discussion with GSFC's EMAC group about synergies
- ADS library of relevant publications (also on slack)

Community Engagement
- QuantHab slack channel (65 members)
- Email list (40 members)
- Workshop (100 participants)

Bi-weekly Meetings (Nov 2020 – Dec 2021)



Daniel Apai 11:23 AM

Dear QuantHab Science Working Group,

Our next meeting will be on the coming **Friday, May 28, 9-10am PDT** (9-10am MST, 12-1pm EDT, 6-7pm CET, 5pm GMT/UTC),

Tentative Agenda for the meeting:

1) Welcome, zoom setup, review of agenda (Apai/Barnes, 5 minutes)
2) News & Announcements (All, 10 minutes)
3) Science Highlight – Patrick Barth: Magma ocean evolution of the TRAPPIST-1 planets (20 minutes)
4) Updates on Literature Review (All, 20 minutes)
5) Summary of action items (Barnes, 5 minutes)

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Zoom connection info:

https://arizona.zoom.us/j/84708859043

Password: QuantHab!

For the full information please see the end of the email

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Literature overview, resources, science program for seminars and workshop, discussions

Several discussions on Astro2020

Speakers included:

Noah Tuchow

Tim Licthenberg

Laura Amaral

Sebastiaan Krijt

Patrick Barth

Antonin Affholder

Avi Mandell

RJ Graham

Jeremy Dietrich

Abel Mendez

QuantHab Science Workshop - Dec 2020

Quantitative Habitability SWG

December Meeting Program

December 14 Time (MST)	Title / Topic	Duration	Speaker	Chair: Daniel Apai
8:00-8:20	Welcome, meeting goals, program, logistics, introductions	20	Daniel Apai	
8:20-9:00	**Guided Discussion – What factors make a planet's surface habitable?** (Necessary / Sufficient conditions for surface habitability, general limits/requirements of surface life as we can tell)	Discussion 25+10	Daniel Apai	
	Science Highlights (12+8 minutes):			
9:00-9:20	The Role of Orbital Dynamics In Planetary Habitability	12 + 8	Stephen Kane (UC Riverside)	
9:20-9:40	Land planets in a ROCKE-3D perturbed parameter ensemble: Climatologies and water distributions.	12 + 8	Nancy Kiang (NASA GISS)	
9:40-10:00	Break / Chat	30		
10:00-10:40	The Evolution of Earth and Its Biosphere	Review, 25+10	Stephanie Olson (Purdue)	
10:40-11:00	Strategy for Quantifying Habitability: Product/Outcome definition [Discussion]	20		
December 16 Time (MST)	**Title / Topic**		**Speaker**	**Chair: Rory Barnes**
8:00-8:10	Welcome, logistics, introductions	10 minutes	Rory Barnes (U Washington)	
8:10-8:50	Key lessons from the evolution of potentially habitable rocky worlds in the Solar System	Review, 25+10	Michael Way (NASA GISS)	
	Science Highlights (12+8 minutes):			
8:50-9:10	A massive hydrogen-rich Martian greenhouse recorded in D/H	12 + 8	Kaveh Pahlevan (SETI)	
9:10-9:30	A Matter of Time: The Coupled Role of Stellar Abundances, Exoplanet Radiogenic Heat Budgets and Climatic Evolution	12 + 8	Cayman Unterborn (ASU)	
9:30-9:50	Understanding the Impact of Stripped sub-Neptunes on EtaEarth using TESS	12 + 8	Rachel B. Fernandes (UArizona)	
9:50-10:00	Break / Chat			
10:00-10:40	Habitability Beyond Sun-like Stars	Review, 25+10	Rory Barnes (UWashington)	
10:40-11:00	Toward a Working Definition of Habitability: Criteria for Habitability/Uninhabitability [Discussion]	20	Lead: Rory Barnes (UWashington)	
December 17 Time (MST)	**Title / Topic**		**Speaker**	**Chair: Johnny Seales**
8:00-8:10	Welcome, program, logistics, introductions	10 minutes	Johnny Seales (Rice U)	
8:10-8:50	Observing Planets at Interstellar Distances	Review, 25+10	Aki Roberge (NASA GSFC):	
	Science Highlights (12+8 minutes):			
8:50-9:10	Deep Imaging of Nearby Habitable Zones with VISIR-NEAR and an Upgraded LBT	12 + 8	Kevin Wagner (UArizona)	
9:10-9:30	Bioverse: a simulation framework to assess the statistical power of future biosignature surveys	12 + 8	Alex Bixel (UArizona)	
9:30-9:50	A thermodynamic-ecological approach of habitability and biosignatures	12 + 8	Regis Ferriere (UArizona)	
9:40-10:00	Break / Chat			
10:00-10:45	Adoption of Working Definition of Habitability [Discussion]	45		
10:45-11:00	Workshop summary and Next Steps	15	Daniel Apai (UArizona)	

Literature Review / Working Document for a Community-driven Perspective on an Applicable, Quantitative Assessment of Habitability

1. What factors make a scientific terminology (system) good?
    - Criteria, good and bad examples for scientific terms
2. Habitability: Criteria, Factors, Considerations
    - Survey of relevant terminology
    - Historical Overview
    - Summary of factors considered in the literature
3. Use Cases
    - Exploratory/Preparatory Observations
    - Target Selection and Prioritization
    - Interpretation of Biosignatures in the Context of Habitability
4. Pitfalls and Limitations
5. Applicability and Observability
6. Frameworks and Use of Terminology in the Literature
    - Including HabEx Final Report, LUVOIR Final Report, NAS Report on Exoplanet Strategy, NAS Astrobiology Strategy Report, NSF Exoplanet Exploration Roadmap, Astro2020 Report

On Overleaf, in prep.

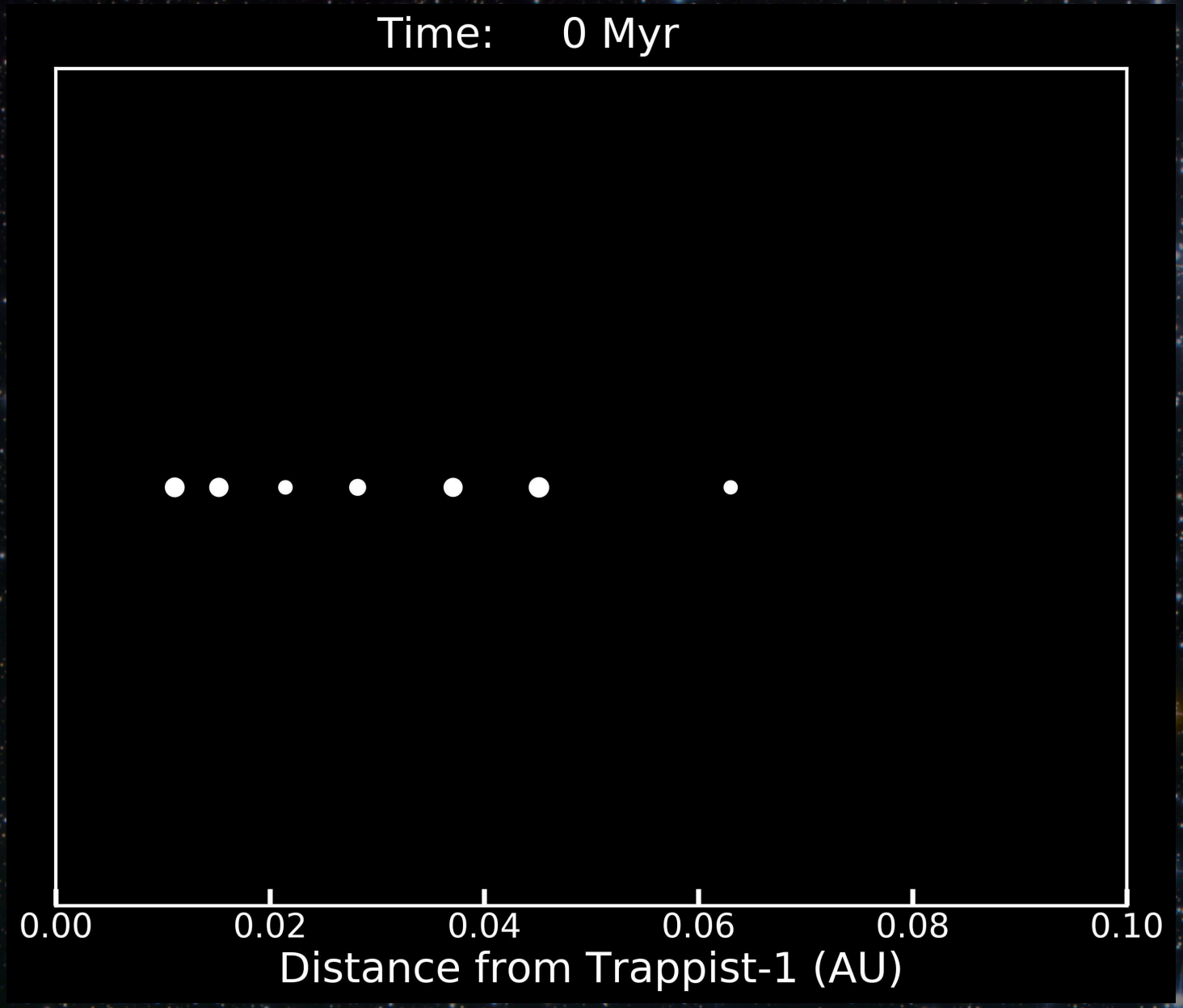
Current Status and Plans

Apai rotating out as Co-Chair this year
Search for New Co-chair to begin this summer
We now meet monthly
Immediate goal is to complete the review paper

Thank you!

Backup Slides

A Concrete Example: TRAPPIST-1 e



TRAPPIST-1 dims for ~1 Gyr

Colors represent habitable zone

XUV radiation can photolyze water

Hydrogen escapes

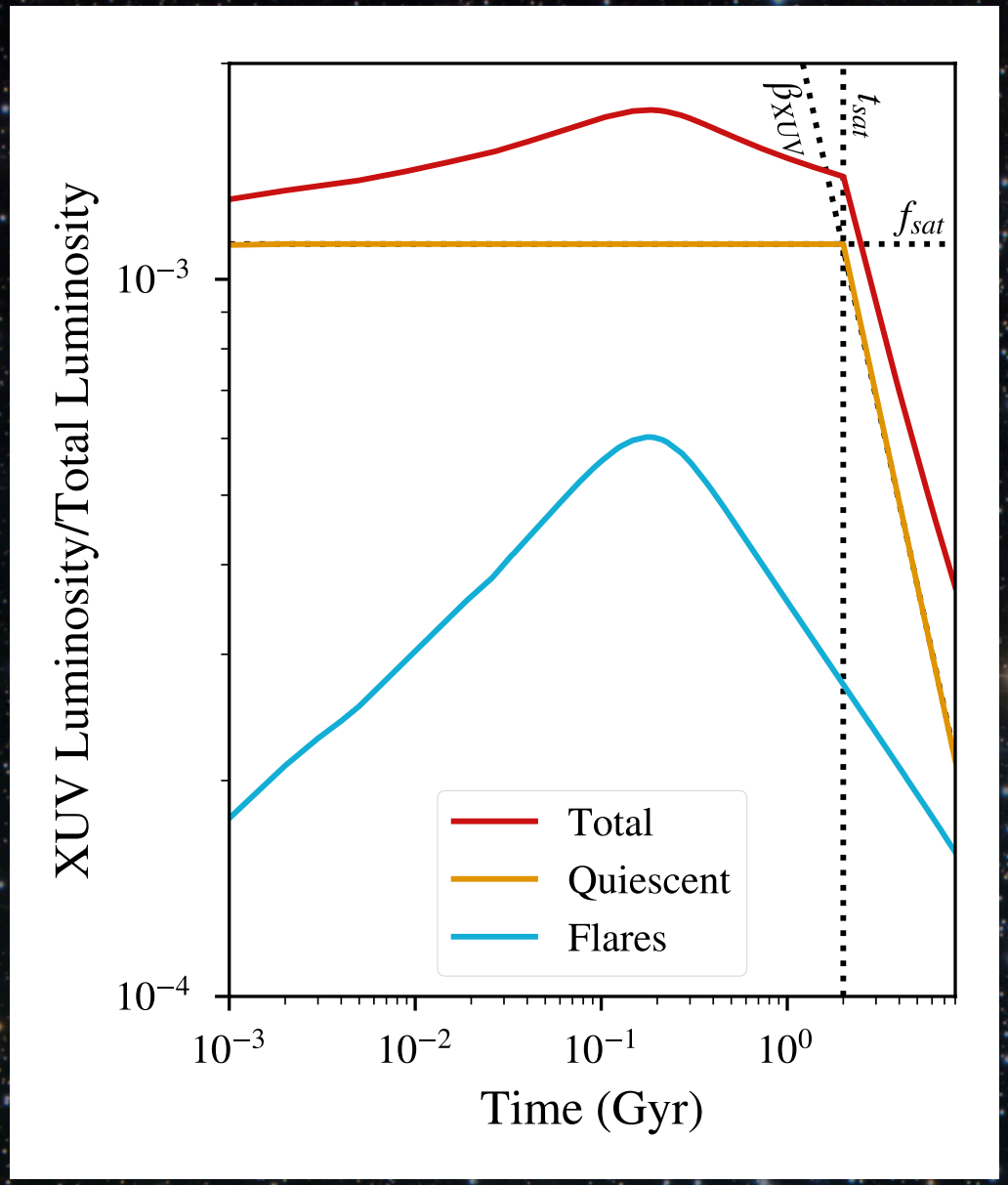
Water lost, oxygen accumulates

If all water is lost, planet is sterile

How *likely* is this scenario?

Adapted from Luger & Barnes (2015)

A Concrete Example: TRAPPIST-1 e



A possible history of the star's XUV luminosity

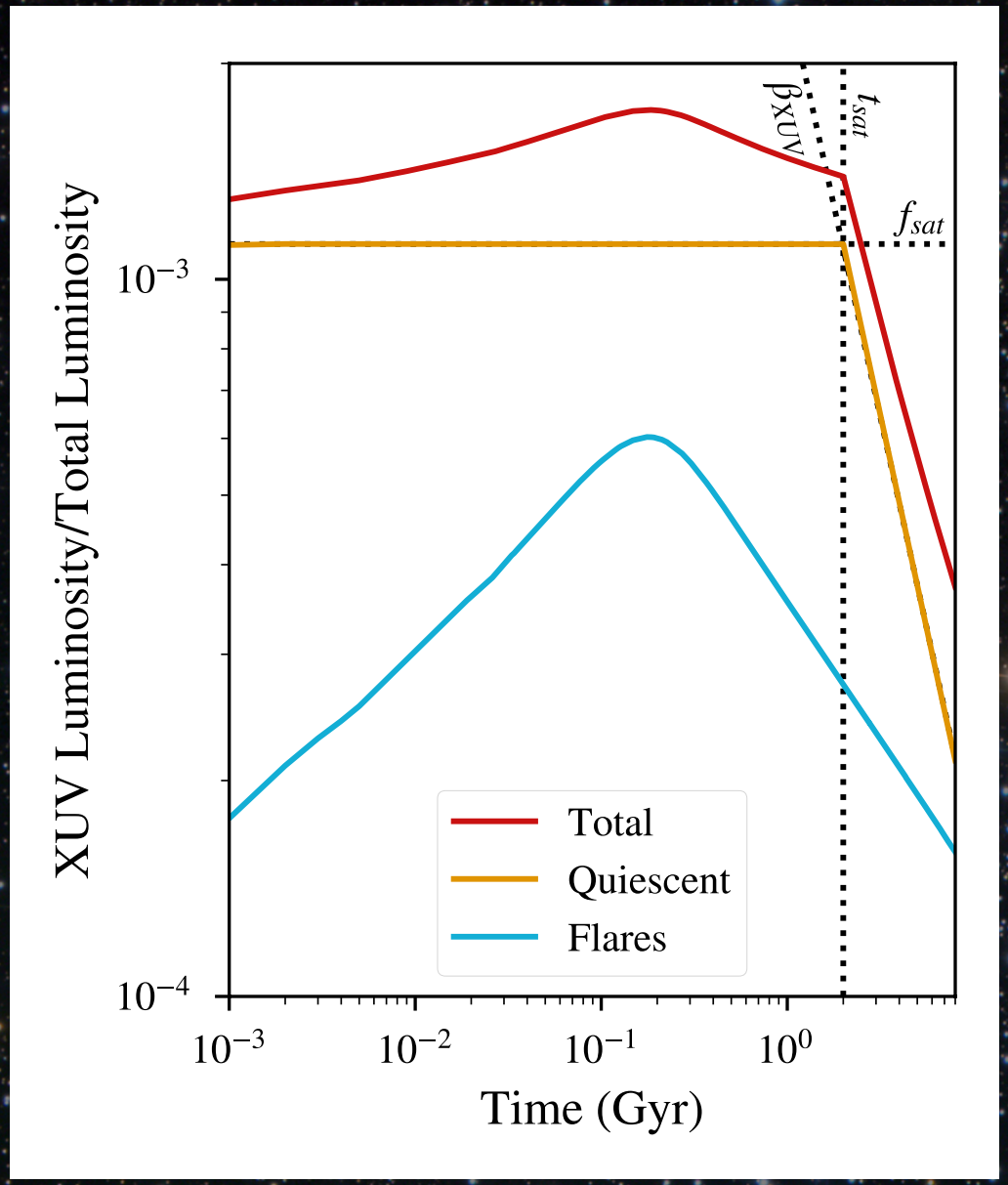
t_{sat} is the "saturation time"

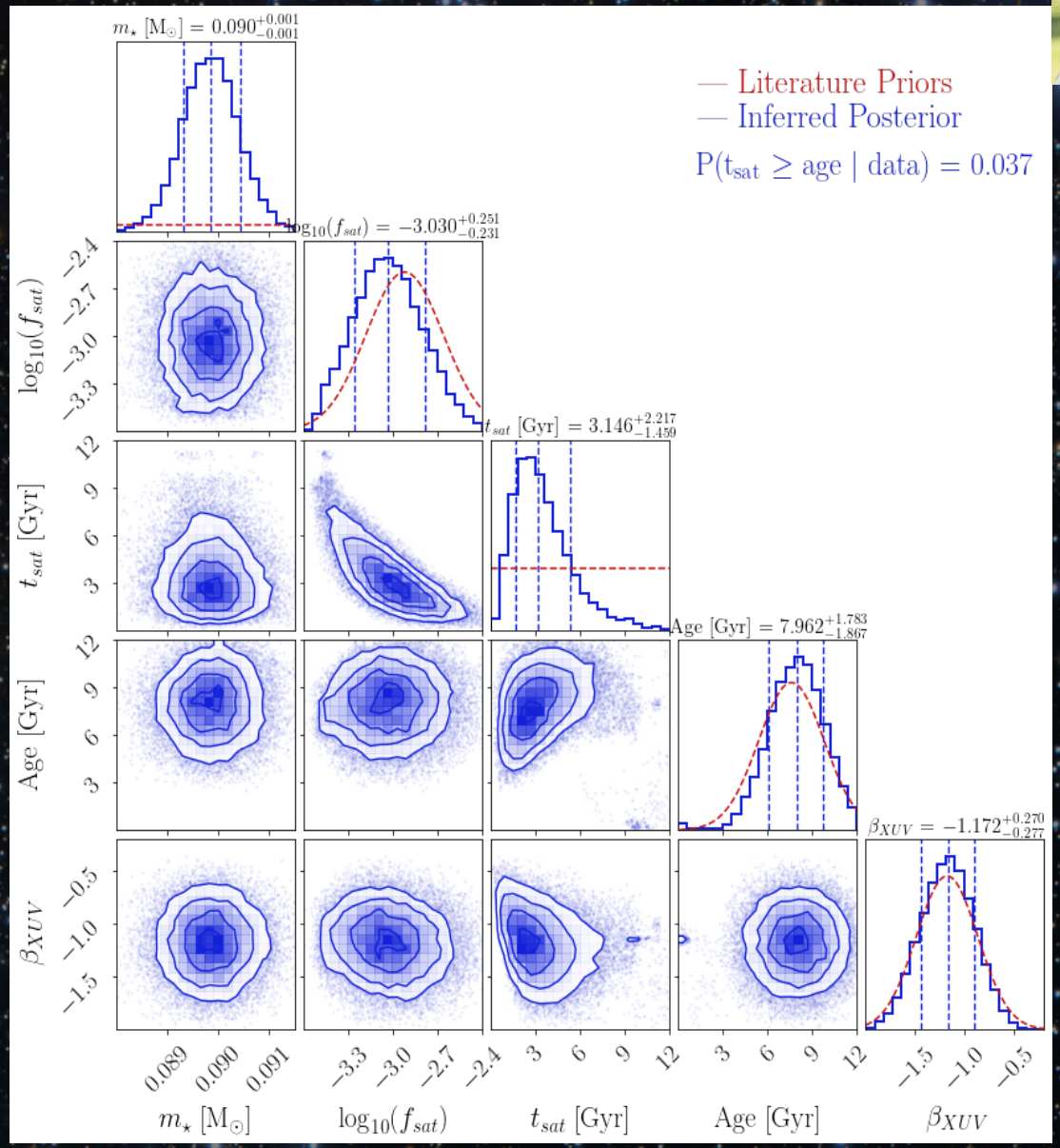
f_{sat} is the fraction of luminosity in the XUV

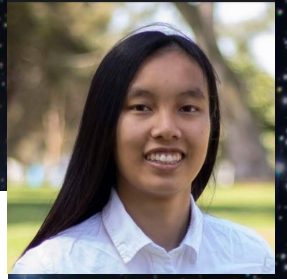
β_{XUV} is power law decline after t_{sat}

To quantify habitability we must constrain the values of these parameters from observations

A Concrete Example: TRAPPIST-1 e







Jessica Birky

Birky et al. (2021)

A Concrete Example: TRAPPIST-1 e

Megan Gialluca